THE EFFECTS OF ELEVATED ATMOSPHERIC CO_2 ON ACID-BASE BALANCE AND RED-CELL ELECTROLYTES OF FBM SUBMARINE CREW MEMBERS

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SUMMARY PAGE

THE PROBLEM

To determine the effects of slightly elevated atmospheric CO_2 during submarine patrol on plasma and red-cell pH, pCO_2, and electrolytes.

FINDINGS

There is evidence suggesting the existence of a mild respiratory acidosis as indicated in the slight fall of red cell pH, decrease in plasma chloride, and increase in red-cell chloride after seven days of exposure. A cation shift consisting of an increase in red-cell sodium and decrease in red-cell potassium was observed after forty-two days of exposure.

APPLICATION

The report will be of interest to those interested in submarine medicine, as well as all physicians, especially those concerned with acid-base changes in health and respiratory diseases.

ADMINISTRATIVE INFORMATION

This investigation was conducted as a part of the Bureau of Medicine and Surgery Research Work Unit MR011.01-5024 - The Effects of Chronically Elevated Carbon Dioxide Levels on Red Cell and Plasma Electrolytes of FBM Personnel. The present report is No. 1 on this Work Unit. The manuscript was approved for publication on 6 December 1971 and designated as Naval Submarine Medical Research Laboratory Report No. 692.

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ABSTRACT

Blood from twelve volunteers serving on a submarine and breathing elevated levels of CO_2 was analyzed for electrolyte, pH, and pCO_2 levels in the plasma and in red-cell hemolysates. The method for measuring pH and pCO_2 in frozen samples entails certain difficulties due to loss of CO_2 during storage. Empirically determined correction factors were used for pH and pCO_2. After seven days of exposure to the submarine atmosphere, red cell pH was found to be statistically significantly lower, than control values while plasma pH showed only a tendency to decrease; plasma chloride was decreased and red cell chloride increased. These findings were considered as evidence suggesting existence of a mild respiratory acidosis. After forty-two days of exposure plasma chloride was still significantly reduced and red-cell chloride slightly elevated. Moreover, red-cell sodium was increased and red-cell potassium decreased, while pH values of plasma and red cells did not differ significantly from control levels. The electrolyte shifts observed after forty-two days have been interpreted as evidence suggestive of an existing acidosis.

THE EFFECTS OF ELEVATED ATMOSPHERIC CO_2 ON ACID-BASE BALANCE AND RED-CELL ELECTROLYTES OF FBM SUBMARINE CREW MEMBERS

INTRODUCTION

It is of interest to know whether submarine personnel breathing elevated levels of CO_2 during prolonged periods of submergence develop changes in blood electrolyte balance similar to those observed in man during prolonged exposure to a level of 1.5% CO_2[4], in patients with respiratory insufficiency and hypercapnia[3,6] and animals exposed to yet higher CO_2 levels[2]. In order to detect changes in plasma and red-cell electrolytes, pH, and pCO_2, we examined twelve volunteers serving on board a nuclear submarine.

METHODS

Twelve subjects were studied before, during and after a submerged period of nine weeks, during which time they breathed air containing a mean concentration of 0.9% CO_2 (time weighted average) Venous blood samples were drawn from each subject once before submerging, three times during the patrol (at 7, 21 and 42 days after submerging), and three days after surfacing. All samples were collected into heparinized glass vacuum tubes and centrifuged immediately. The plasma and red-cell portions were separated anaerobically and stored in capped plastic syringes at -15°C. Analysis was performed at a later date.

Van Slyke[7] has pointed out the necessity of correcting plasma pH for an alkaline error of 0.03 pH units resulting from centrifugation of the samples at room temperature. All pH units have been corrected in this manner.

It became apparent that frozen venous blood samples stored in capped plastic syringes will decrease in pCO_2 and increase in pH levels, while bicarbonate levels remain unchanged. In a control study, six of the 12 subjects were sampled for venous plasma, pH and pCO_2 levels: Test samples were made (a) immediately after centrifugation, (b) after 17 days' storage at -15° C, and (c) after 120 days at -15°. From the plot of the data it was found that pH increased and that log pCO_2 decreased linearly. The following correction factors were derived from the data:

(a) correction for pH = -0.003 pH units per day frozen

(b) correction for pCO_2 = +log 0.3 mm Hg pCO_2 per day frozen

During submergence, the ship's atmosphere was monitored at four hour intervals with installed and portable analyzing devices. CO_2 levels varied between 0.65% and 1.2% with a mean of 0.9%. Oxygen levels varied between 19 and 21%. Other gases present in measurable quantities included freon-12 (maximum 25 ppm) and carbon monoxide (maximum 30 ppm).

Students _t_ test was employed for statistical analysis of the data.

RESULTS

Acid-base values for plasma and hemolyzed red cells are given in Table I. There was a tendency for plasma pH to decrease and a statistically significant decrease in red-cell pH after 7 days. An increase in red-cell pCO_2 was noted after 21 and 42 days.

Table I. Effect of Prolonged Exposure to 0.9% CO_2 During Patrol on Plasma and Red Cell pH, P_{CO_2} and Bicarbonate

		PLASMA pH	PLASMA P_{CO_2} mm Hg	PLASMA HCO_3 mEq/1	RED CELL pH	RED CELL P_{CO_2} mm Hg
Control	Mean	7.346	52.9	27.8	7.173	55.8
	S.E.	.008	.8	.5	.004	1.5
	N	12	12	12	12	12
PATROL 0.9% CO_2						
7 days	Mean	7.329	55.6	28.0	7.144*	54.0
	S.E.	.009	1.3	.9	.008	4.6
	N	12	12	12	12	12
21 days	Mean	7.359	48.6	26.4	7.160	62.8*
	S.E.	.010	1.0	.5	.007	1.9
	N	11	11	11	11	11
42 days	Mean	7.364	47.6*	26.3	7.144	59.7
	S.E.	.009	1.0	.6	.008	5.9
	N	12	12	12	12	12
Recovery 3 days	Mean	7.405	44.0*	26.9	7.182	53.0
	S.E.	.006	1.0	.6	.007	1.8
	N	11	11	11	11	11
Recovery 17 days	Mean	7.332	54.8	28.0	7.134	61.5
	S.E.	.013	.6	.4	.008	1.7
	N	6	6	6	6	6

*Statistically significant difference from controls at the 5% level and better

Plasma and red-cell electrolyte values are given in Table II. Plasma sodium, potassium, and chloride values decreased during CO_2 exposure. In red cells there was a statistically significant rise in sodium and chloride, and a fall in potassium during CO_2 exposure. For comparison, data on plasma chloride and bicarbonate obtained by Mendelson, on an FBM patrol are included in Table III.

Eable II. Effect of Prolonged Exposure to 0.9% CO_2 During Patrol on Plasma and Red Cell Electrolytes (12 Subjects)

		PLASMA			RED CELL		
		Na mEq/1	K mEq/1	C1 mEq/1	Na mEq/1	K mEq/1	C1 mEq/1
Control	Mean	140.7	3.9	103.2	16.0	89.2	63.3
	S.E.	.78	.07	1.17	.7	1.4	1.1
PATROL 0.9% CO_2							
7 Days	Mean	138.2	3.6*	100.1 *	17.5	95.1	68.8*
	S.E.	1.02	.12	.88	1.6	2.5	1.0
21 Days	Mean	138.6	3.8	102.9	17.9	84.3*	63.5
	S.E.	1.15	.16	.81	.8	.8	1.9
42 Days	Mean	136.7*	3.8	100.8*	21.8*	84.3*	67.1
	S.E.	1.24	.17	1.33	1.0	1.3	.7
63 Days plus 3 days recovery on air	Mean	140.4	3.9	103.1	20.8*	86.2	60.5
	S.E.	1.28	.24	.87	.7	2.9	1.9

*Statistically significant difference from controls at the 5% level or better

Table III. Effect of Prolonged Exposure to 0.9% CO_2 During Patrol[1] on Plasma Bicarbonate and Plasma Chloride (8 Subjects)

		PLASMA	
		HCO_3 mEq/L	Cl mEq/L
Control	Mean S.E.	24.3 .5	109.2 .6
Patrol 0.9% CO_2 40 Days	Mean S.E.	23.4 .3	99.1* .9
60 Days + 2 Days Recovery on Air	Mean S.E.	25.0 .6	99.4* 1.7

[1]Data from Mendelson
*Statistically significant difference from CO_2 controls ($P < .001$)

Before interpreting the results obtained, it is necessary to evaluate the weaknesses associated with the method of obtaining blood-samples during an FBM patrol, freezing the samples and analyzing them several week's later.

Mendelson's blood samples were, during the centrifugation period, directly exposed to the submarine atmosphere. Under these circumstances gaseous carbon dioxide diffuses out of the blood into the surrounding air resulting in a decrease in pCO_2 and H^+ concentrations which probably existed in the blood samples obtained during patrol. The bicarbonate levels of Mendelson's samples (Table III) are probably for this reason unchanged.

In this study, the blood samples were obtained under anaerobic conditions and centrifuged under anaerobic conditions.

In spite of these precautions, proper venous blood samples will still lose some CO_2 during storage as pointed out above.

There was a trend towards a decrease in plasma pH and a definite fall of red-cell pH after seven days of exposure. After three and six weeks, the pH in plasma and red cells was again higher and they neared initial levels. These findings suggest that respiratory acidosis produced by prolonged exposure to an average CO_2 concentration of 0.9% CO_2 is most pronounced during the first week.

Studies of chronic hypercapnia in animals[2] and patients with chronic respiratory acidosis[3] have shown that the rise in bicarbonate regularly found in chronic hypercapnia is associated with a reciprocal fall in plasma chloride. The decrease in plasma chloride can therefore provide an indicator of an existing respiratory acidosis when the accuracy of the bicarbonate values is in question. Plasma chloride concentrations were lower than control levels in all exposure periods and this decrease was statistically significant after 7 days and 42 days of 0.9% CO_2 exposure. This finding is in line with that of Mendelson[1], who noted a significant decrease in plasma chloride levels in submarine personnel after 40 days of exposure to 0.9% CO_2.

In Mendelson's study, serum chloride was still significantly below control levels after 2 days recovery following 60 days of exposure to 0.9% CO_2.

In this study, plasma chloride levels were found to have returned to the control value after 3 days of recovery following 63 days of exposure to 0.9% CO_2. In the 42 day study of exposure to 1.5% CO_2, Schaefer, et al[4] observed that more than 9 days of recovery are needed for acid-base parameters to return to control values.

It would be important to obtain more data in order to establish more accurately the time course of recovery of acid-base parameters and particularly plasma chloride. The finding of an increase in red-cell sodium and chloride and a decrease in red-cell potassium is in line with the findings of Schaefer et al[4] in subjects exposed to 1.5% CO_2 levels. This "cation shift" observed in both men and animals has been attributed to changes in red-cell cation permeability. Under higher concentrations of CO_2 cation shifts were found to be caused by inhibition of active transport due to reduction of red-cell glycolysis[5]. During exposure to 1% CO_2 changes in red cell permeability could be caused by increased levels of calcium ions (unpublished observations).

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(PAGE 2)

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